Project Report: Analysis of and Discrimination of TPF Planetary Spectra using Bayesian and Artificial Neural Network Techniques

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Project Progress

The Terrestrial Planet Finder (TPF) mission will use low−resolution, low−sensitivity data to detect and characterize extrasolar terrestrial planets. This task focuses on mathematical techniques to maximize the return from TPF data.

Image Reconstruction and Planet Signal Extraction for TPF−I nulling interferometer Velusamy (with Ken Marsh) has developed an algorithm based on Richardson and Marsh (1983) to reconstruct the image from the SINE/COS chopped output of dual nulling interferometer. This algorithm treats the ensemble of possible images as a Gaussian random process, subject to a positivity constraint, and contains no limitations on the presence of negative lobes in the null response pattern with the chop. The Bayesian procedure maximizes the probability density of the image conditioned on the data. This algorithm will have application in analyzing the spectral features detectable by TPF−I

Using Artificial Neural Networks to Discriminate TPF Spectra
To determine the scientific impact of trade−offs in instrument characteristics (e.g., wavelength coverage, spectral resolution, and signal−to−noise (S/N)) for spectral characterization of terrestrial planets, this task focuses on using Artificial Neural Networks (ANN) to determine instrumentation limits for reliable classification of spectra. As the test set, we have used UV−FIR planetary spectra generated by the Virtual Planetary Laboratory (VPL) and convolved these with slit functions and a simplistic noise model to produce spectra with a range of spectral resolutions and S/N levels. Thousands of ANNs have been run to discriminate these spectra in four wavelength regions, at multiple resolutions (millimeter imaging radiometer (MIR): R = 5 to 100, vis: R = 20−200), and for S/N from 3−100. Multiple versions of the same ANNs have also been run to test for consistency of results. With our simplistic noise model, the ANNs clearly discriminate spectra at very modest resolutions and S/N. Ongoing work involves expanding the test set to other planetary types and working with the TPF design teams to build more realistic noise models.

Highlights

- Based on our preliminary noise model and our ANN analyses, Meadows, Von Hippel, and Tinetti estimate that at S/N ≥5 at R = 25 for 6–17 µm (TPF–I) and a S/N ≥8 at R = 75 for TPF–C 0.5–1.0 µm (TPF–C) the ANNs will provide a certainty of 90% for a correct classification among a basic family of 6 hypothetical, but realistic planets: Earth, Mars, Ancient Earth, Frozen Mars, and Jovian planet at 1 AU. (We do caution, however, that this result is based on a simplistic noise model and these results represent the most optimistic case.)
- Project Scientist Velusamy was a co–I on a successful Spitzer proposal to search for debris disks around nearby stars to characterize likely Space Interferometry Mission (SIM) and TPF target stars in the mid–infrared. These data will help characterize the evolution, amount, structure, and composition of the dust associated with Kuiper and asteroid belts around many types of stars. This characterization of exo–zodiacal light around nearby stars will provide observational input for more realistic noise models for TPF data.

Roadmap Objectives

- ***Objective No. 1.2:*** Indirect and direct astronomical observations of extrasolar habitable planets
- ***Objective No. 7.2:*** Biosignatures to be sought in nearby planetary systems

Mission Involvement

Mission Class*	***Mission Name (for class 1 or 2) OR Concept (for class 3)***	***Type of Involvement*****
2	TPF	Planning Support,Data Analysis,Background Research,Research or Analysis Techniques
2	Spitzer	Background Research

* Mission Class: Select 1 of 3 Mission Class types below to classify your project:
1. Now flying OR Funded & in development (e.g., Mars Odyssey, MER 2003, Kepler)
2. Named mission under study / in development, but not yet funded (e.g., TPF, Mars Lander 2009)
3. Long–lead future mission / societal issues (e.g., far–future Mars or Europa, biomarkers, life definition)

** Type of Involvement = Role / Relationship with Mission
Specify one (or more) of the following: PI, Co–I, Science Team member,

planning support, data analysis, background research, instrument/payload development, research or analysis techniques, other (specify).

This project work is specifically being used to identify and estimate the detectability of terrestrial planet characteristics in disk−averaged spectra for Earth−like planets orbiting other stars, as an aid to understanding what can be learnt about extrasolar terrestrial planets from astronomical observations. This work is therefore background science for the TPF mission and will provide information that will be valuable for mission planning, including estimates of the minimum and optimum sensitivity, wavelength range and spectral resolution required for both TPF−I and TPF−C, especially when attempting to characterize terrestrial planets around TPF target stars of different spectral type. Vikki Meadows is a member of the TPF Science Working Group and has served as an advisor and reviewer for specific tasks related to developing TPF science requirements. The Spitzer work successfully proposed by team member Velusamy and colleagues uses a NASA Origins mission to support the search for life beyond the solar system by starting the detailed characterization of nearby stars that are potential targets for SIM and TPF. This information is crucial not only to allow us to chose the target stars that are most likely to provide optimum detectability and habitability for orbiting terrestrial planets, but to provide valuable input on levels of exo−zodiacal light, which is likely to be a significant noise source for the detection and characterization of terrestrial planets, and must be accounted for in realistic models for planetary spectral discrimination.